Permanent Carbon Dioxide Storage in Basaltic Rock

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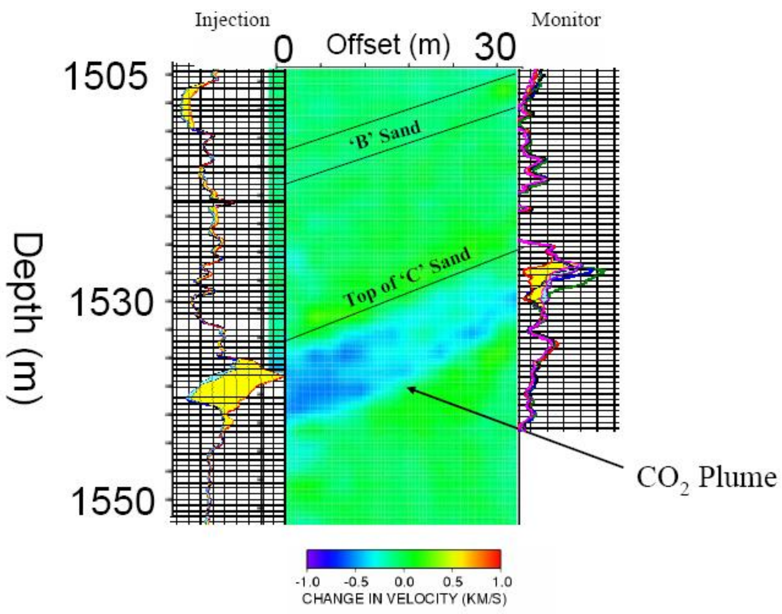
Outline

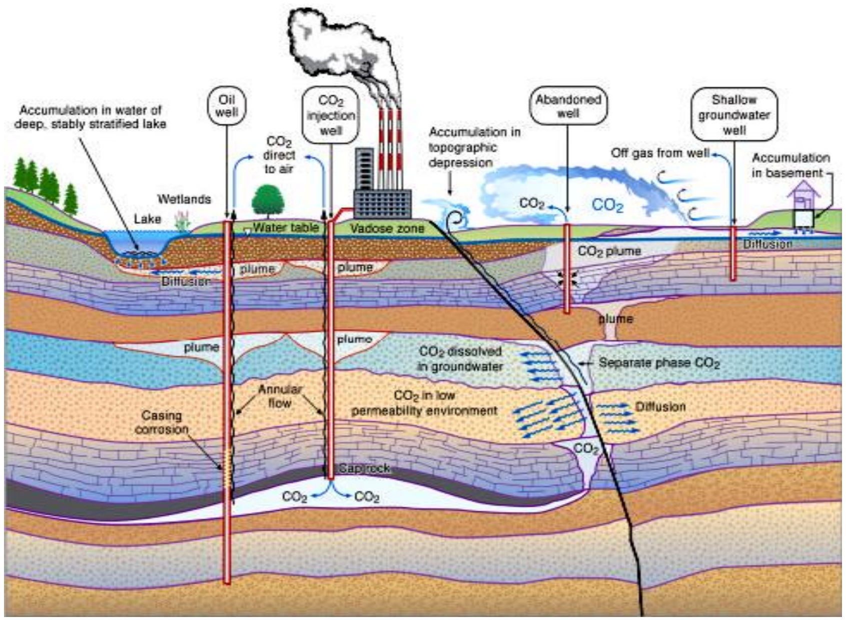
1. Introduction – Motivation
2. CO_2 Storage in Basalt
3. Field Tests
4. Conclusions

Buoyancy and Leakage

- Buoyancy of CO_2
- Leakage and reliability of storage -> **PERMANENCE**



Source: Daley et al. 2005



www.westcarb.org

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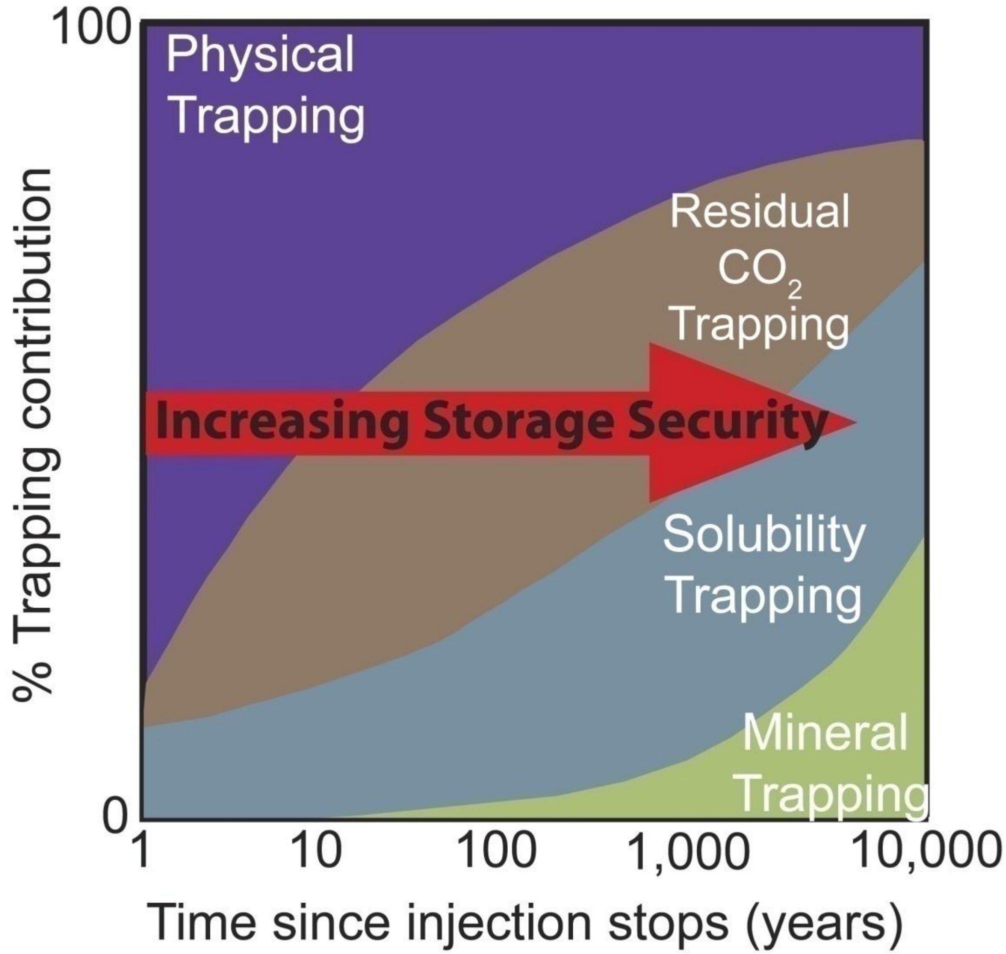
Storage (Trapping) Mechanisms

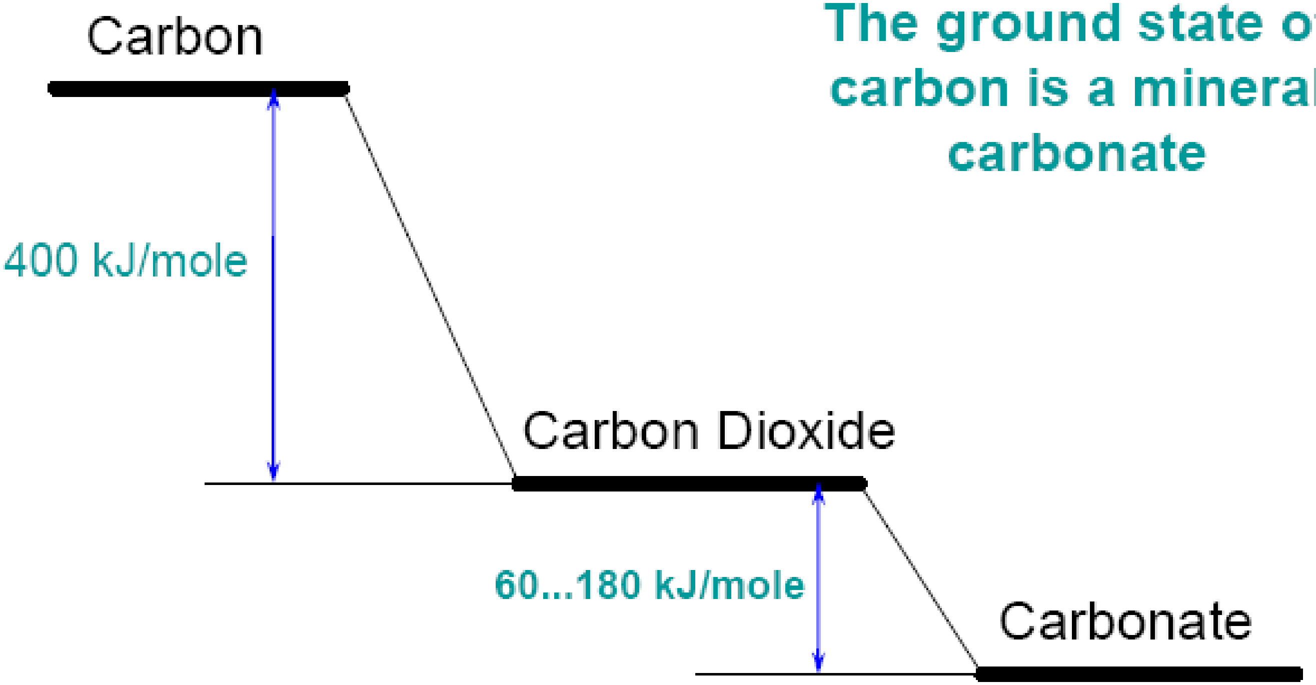


CO_2 will be stored by a combination of physical and chemical trapping mechanism.

Over time residual trapping, solubility trapping , and mineral trapping increase.

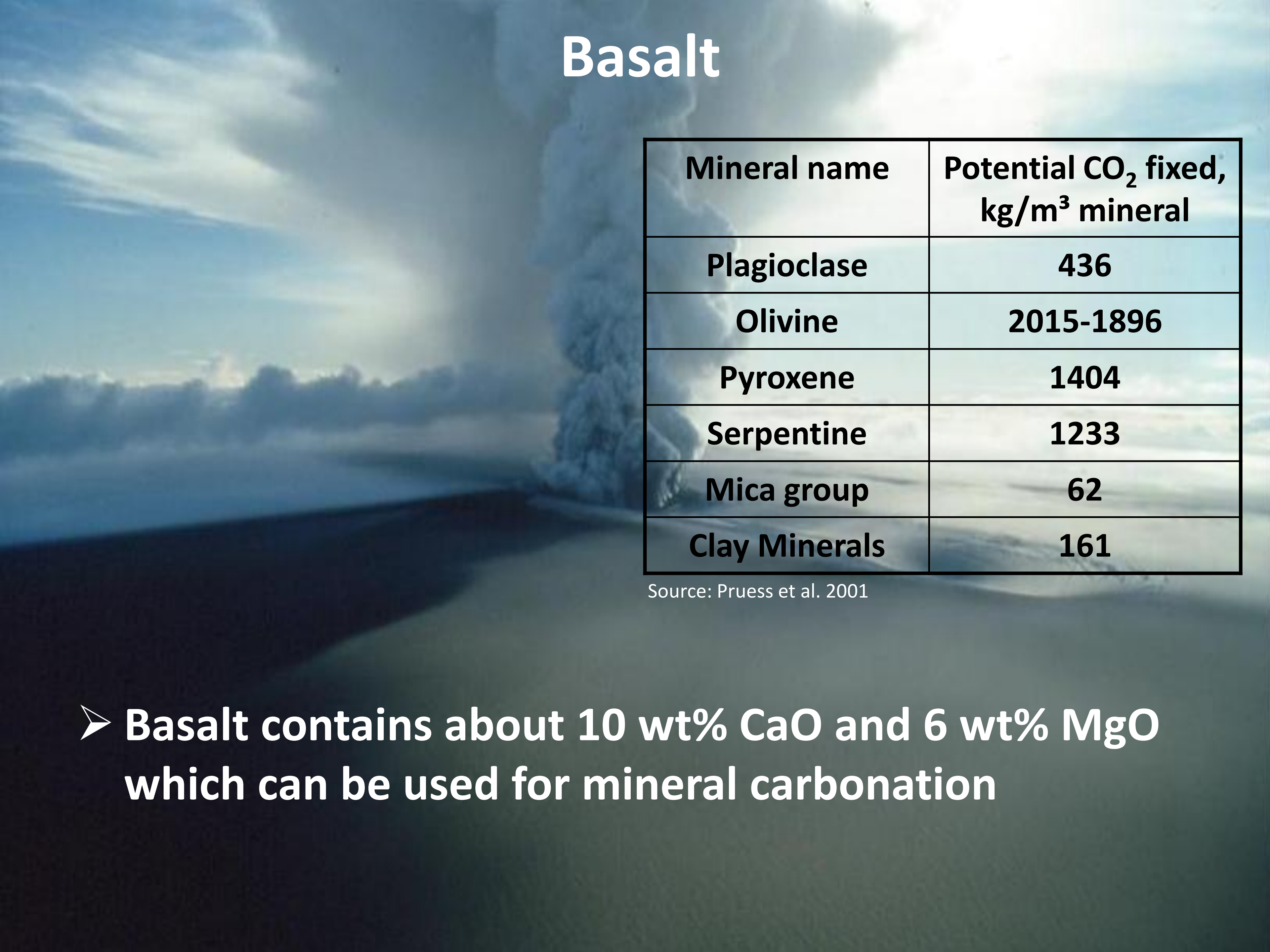
IPCC, 2005: Carbon Capture and Storage Special Report

Energy States of Carbon



The ground state of carbon is a mineral carbonate

Klaus Lackner, 2004



Basalt

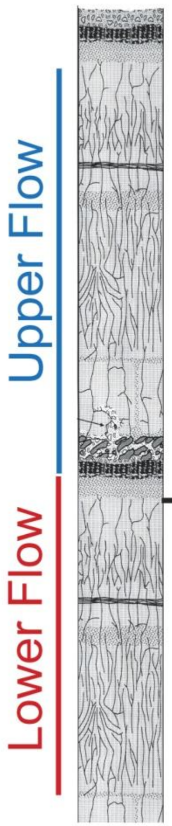
Mineral name	Potential CO_2 fixed, kg/m³ mineral
Plagioclase	436
Olivine	2015-1896
Pyroxene	1404
Serpentine	1233
Mica group	62
Clay Minerals	161

Source: Pruess et al. 2001

- **Basalt contains about 10 wt% CaO and 6 wt% MgO which can be used for mineral carbonation**

Flood Basalt

Flood Basalt Features (e.g. Columbia River Basalt)



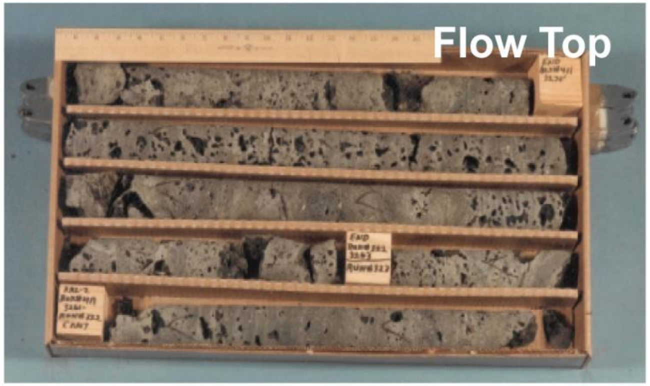
Flow Top:
high permeability,
target injection zone

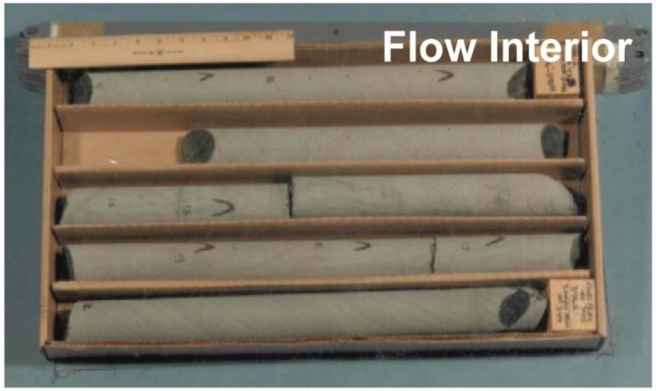
Flow Interior:
low permeability,
cap rock (seal)

Flow Bottom

Flow Top: vesicular to rubbly, and/or brecciated

Flow Bottom: vesicular to rubbly, and/or brecciated

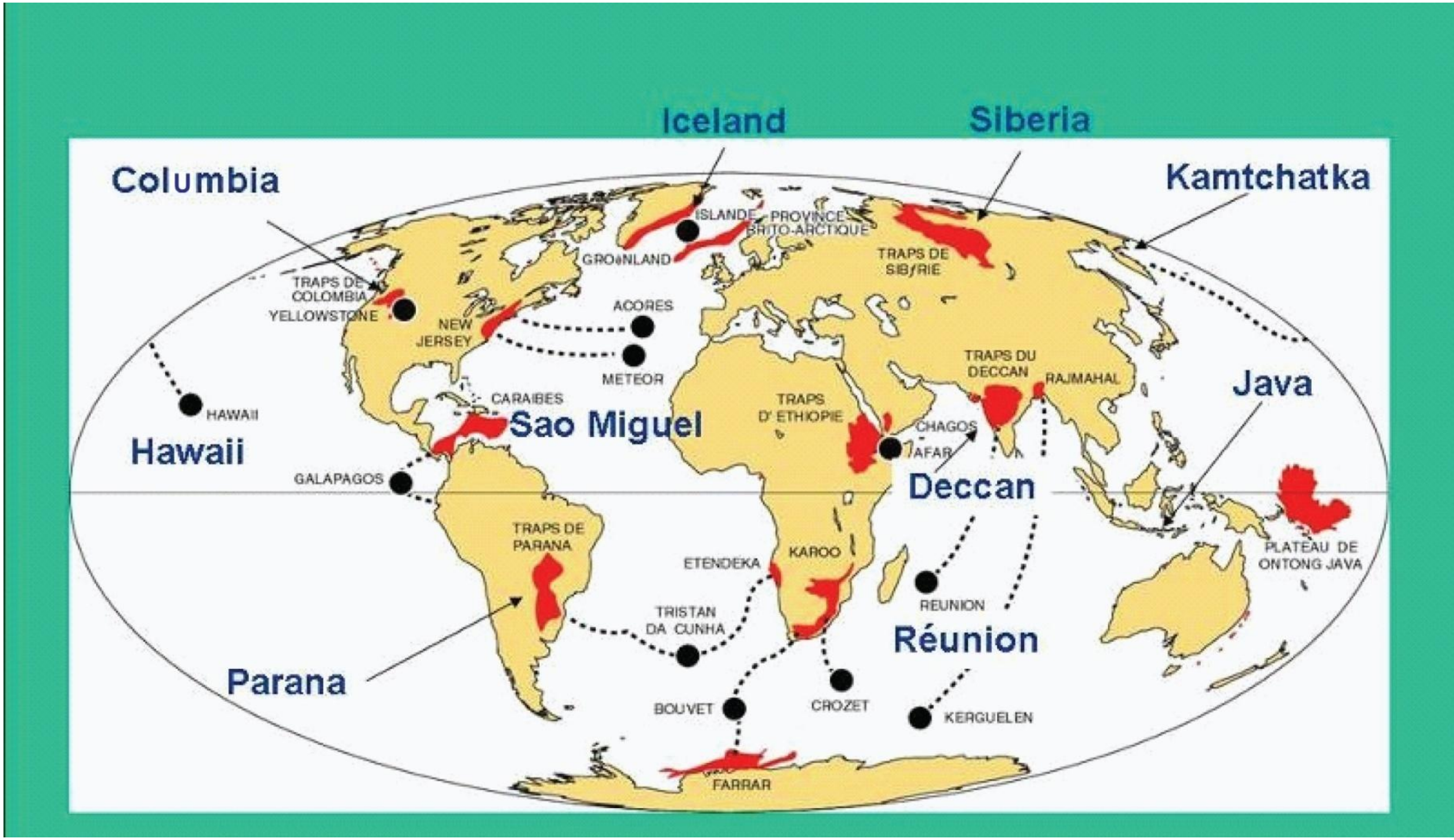




Source: Wintczak, TM, 1984. “Principal bore-hole report - borehole RRL2” SD-BWI-TI-113, Rev. 1, Rockwell Hanford Operations, Richland, WA

Global Significance

- Extensive basalt shields worldwide



In Situ Mineral Carbonation

Dissolution of CO_2 and Dissociation

$$CO_2(g) \overset{K_h}{=} CO_2(aq)$$

$$CO_2(aq) + H_2O \overset{K_1}{=} HCO_3^- + \mathbf{H^+} \overset{K_2}{=} CO_2^{3-} + \mathbf{2H^+}$$

Mineral Dissolution

$$Mg_2SiO_4 + \mathbf{4H^+} \xrightarrow{k_1} 2Mg^{2+} + SiO_2 + 2H_2O$$

$$CaAl_2Si_2O_8 + \mathbf{2H^+} + H_2O \xrightarrow{k_2} Ca^{2+} + Al_2Si_2O_5(OH)_4$$

?

Mineral Precipitation

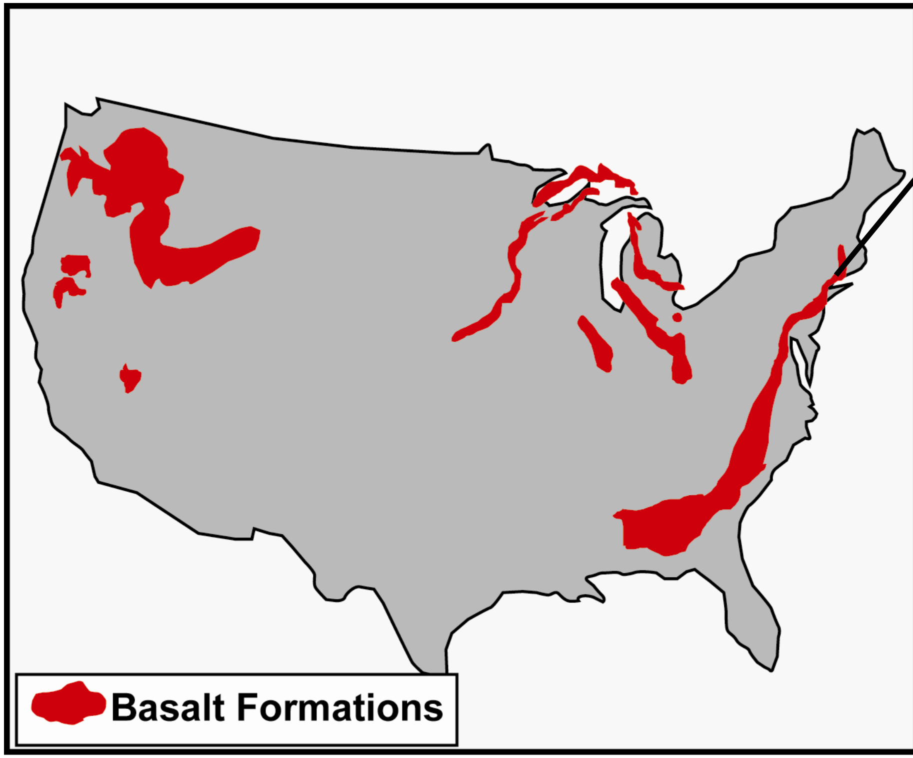
$$(Ca^{2+}, Mg^{2+}, Fe^{2+}) + CO_3^{2-} \overset{K_3}{=} (Ca, Mg, Fe)CO_3(s)$$

CO_2 Immobilization

$$+ \; CO_2(aq) \; =$$

Calcium - Magnesium Silicate Rock + Dissolved CO_2 = (Ca, Mg, Fe) Carbonate

Palisades Sill – Newark Basins



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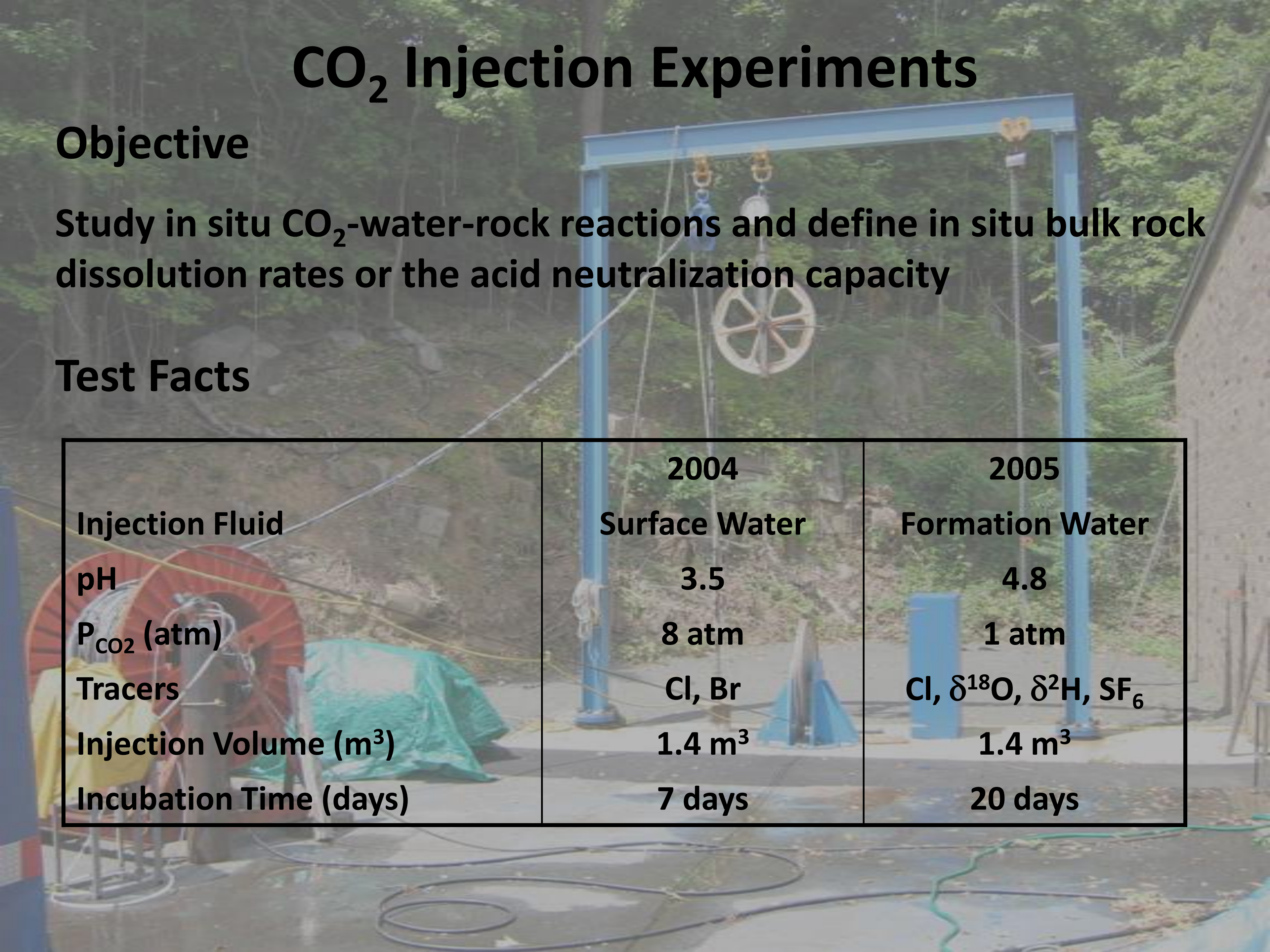


CO_2 Injection Experiments

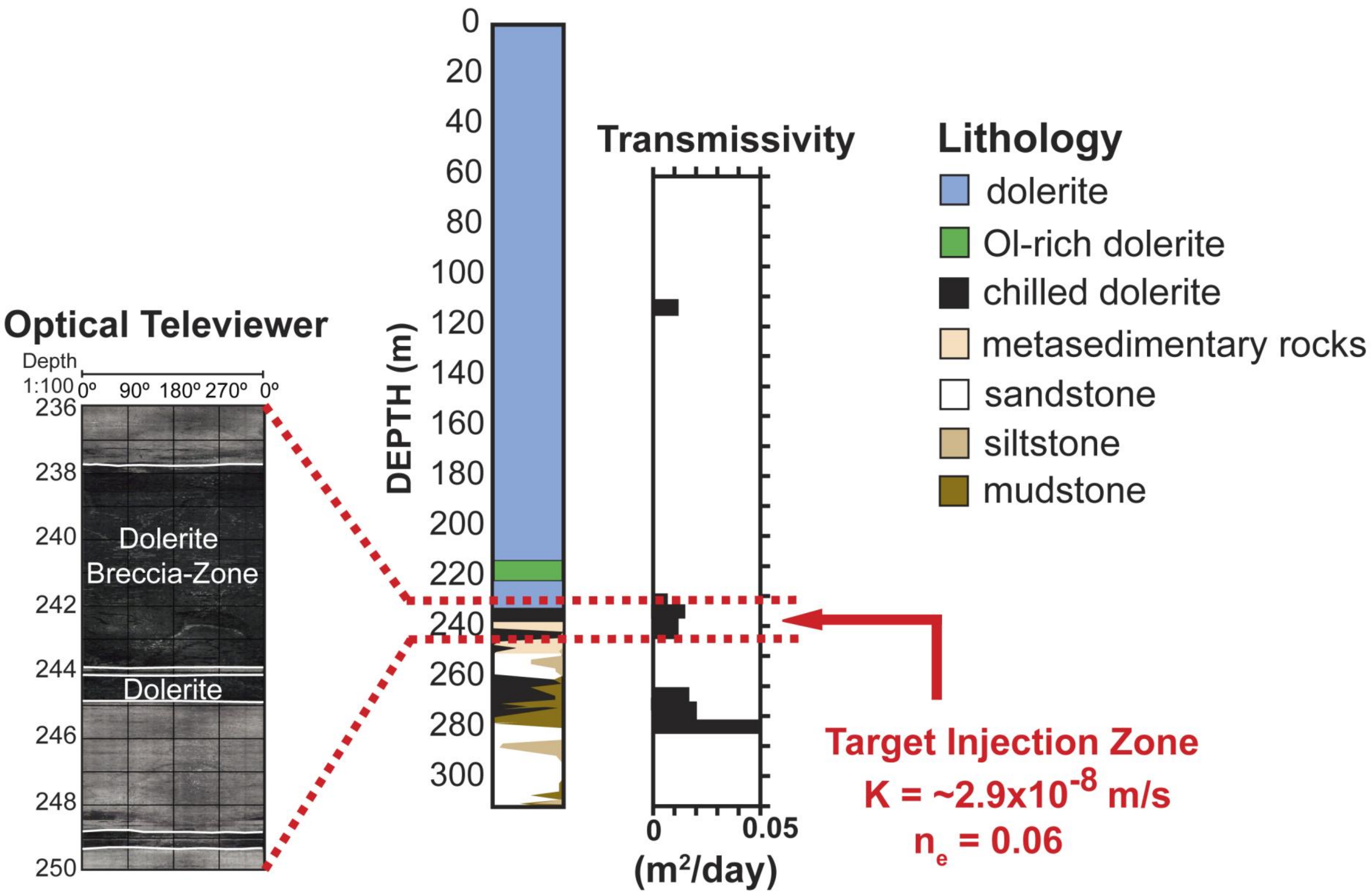
Objective

Study in situ CO_2-water-rock reactions and define in situ bulk rock dissolution rates or the acid neutralization capacity

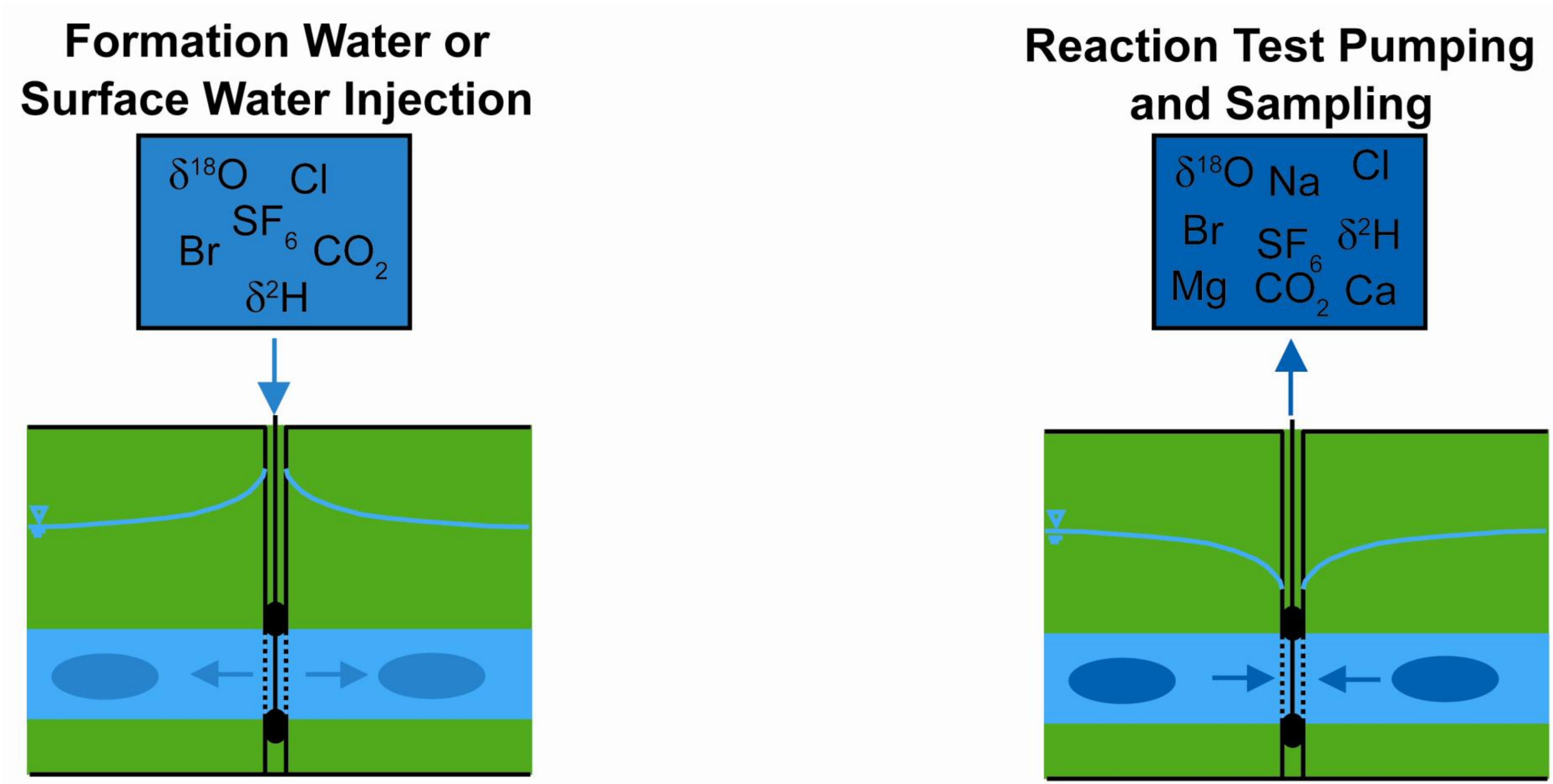
Test Facts

	2004	2005
Injection Fluid	Surface Water	Formation Water
pH	3.5	4.8
P_{CO2} (atm)	8 atm	1 atm
Tracers	Cl, Br	Cl, $\delta^{18}O$, $\delta^{2}H$, SF_6
Injection Volume (m^3)	1.4 m^3	1.4 m^3
Incubation Time (days)	7 days	20 days

CO_2 Injection Zone

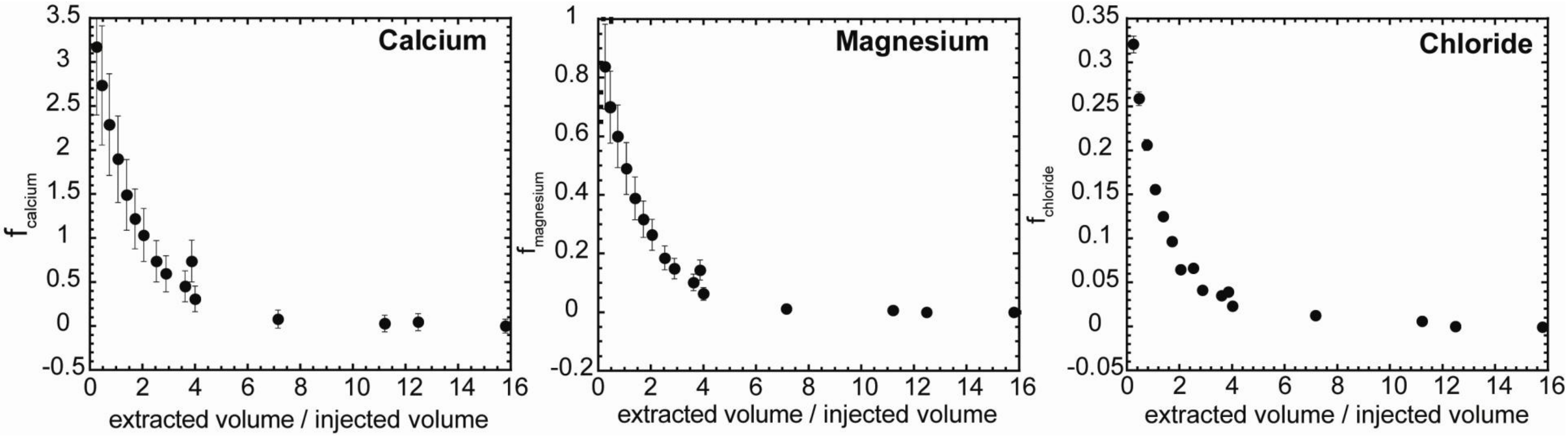


Single Well Push-Pull Test



Injection Phase	Incubation Phase	Pumping Phase
1 day	7 or 20 days	5 to 7 days

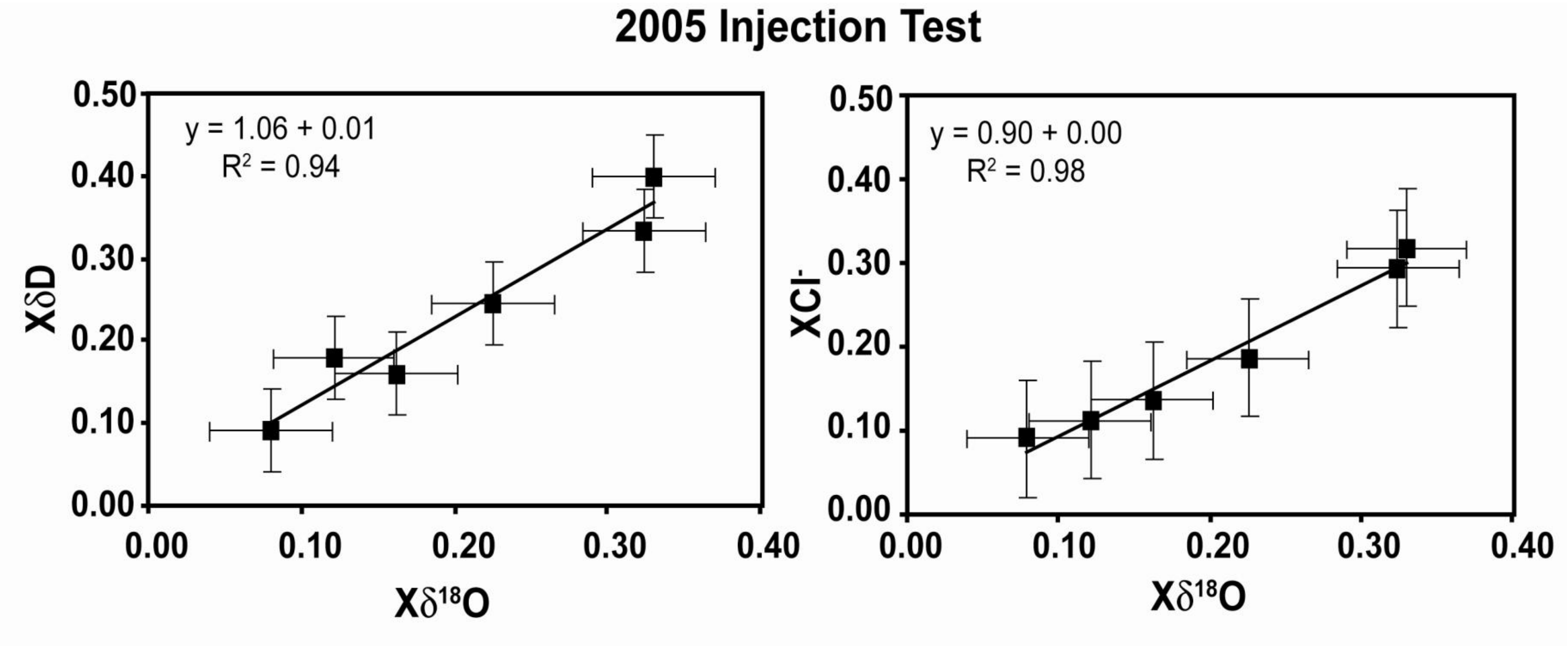
Breakthrough Curves



$$f_i = (C_{measured} – C_{background}) / (C_{injected})$$

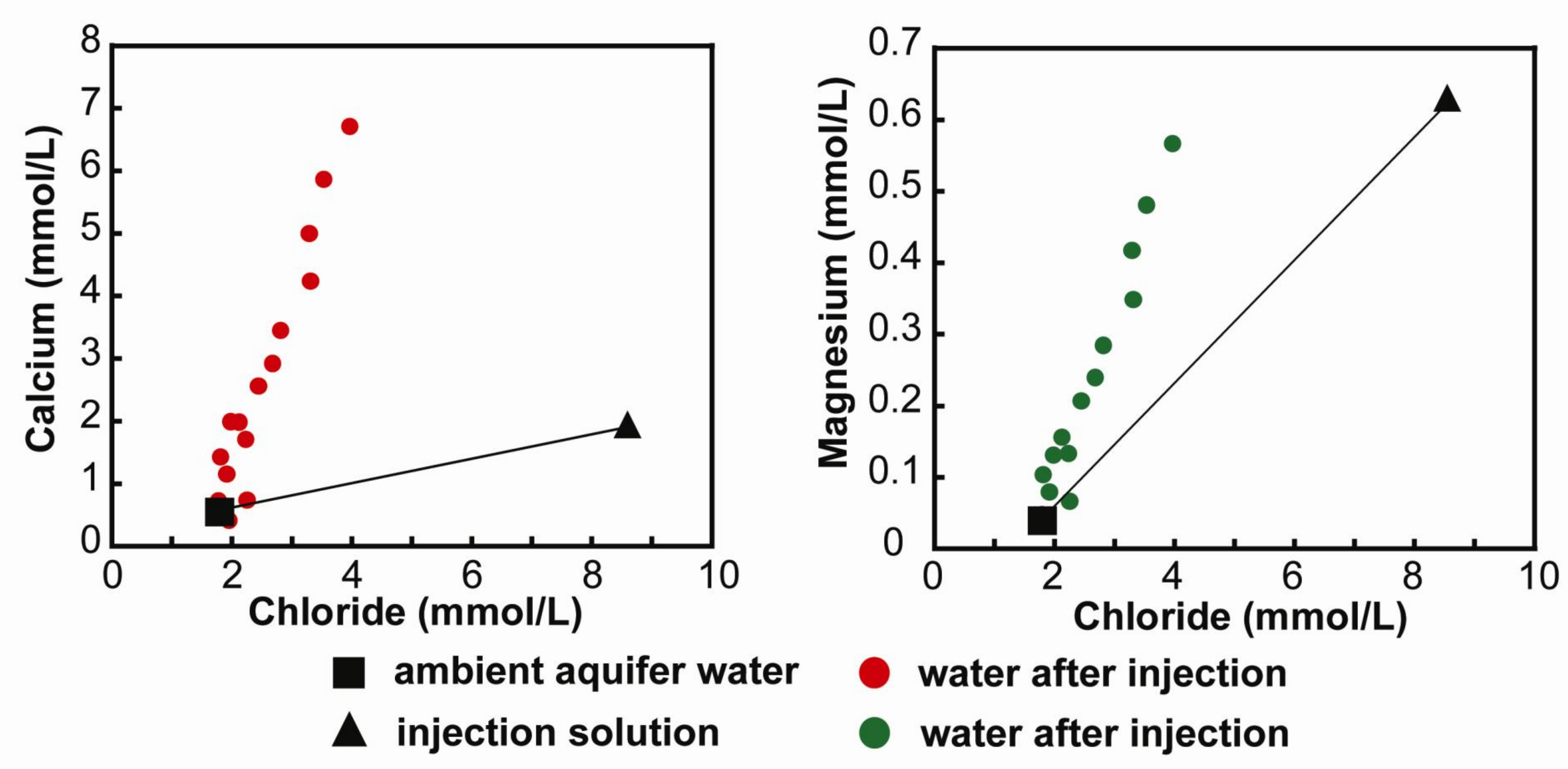
Matter et al. 2007, G^3

Mixing



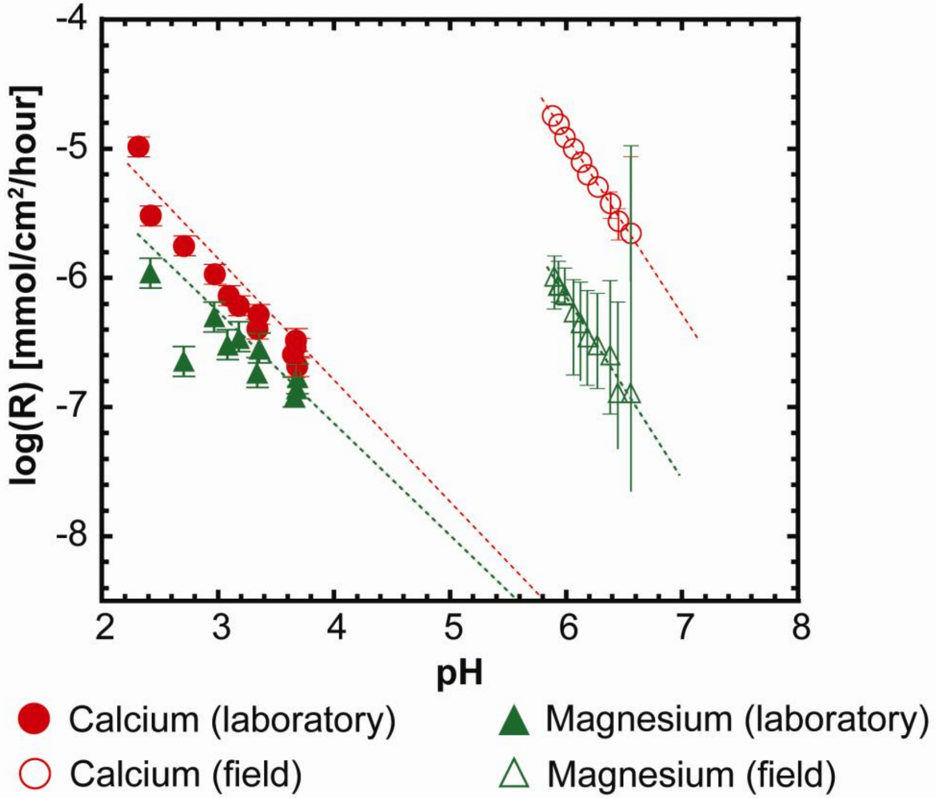
$$[\text{Tracer}]_{\text{ext water}} = X\,[\text{Tracer}]_{IW} + (1-X)\,[\text{Tracer}]_{BW}$$

Water-Rock Reaction



Matter et al. 2007, G^3

Dissolution Rates



$$R = C_{react}(t) \cdot V_{pumped}(t) / t_r \cdot A$$

- Ca-release rate 9x10^{-6} mmol/cm^2/h

-> 0.08 g/m^2/day

- Mg-release rate 5x10^{-7} mmol/cm^2/h

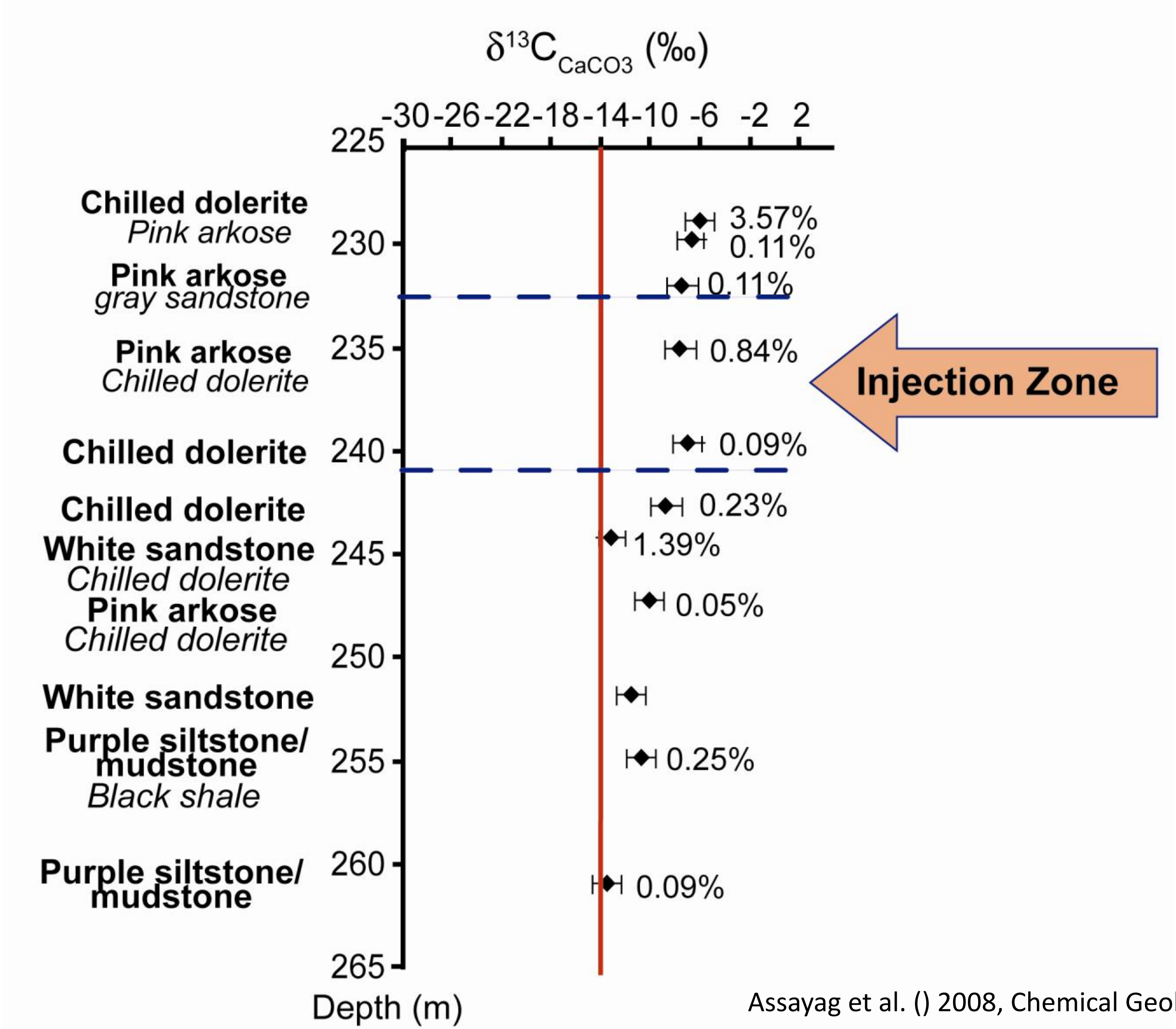
-> 0.003 g/m^2/day

- Columbia River Basalt dissolution rate

0.025 g/m^2/day (McGrail et al. 2006)

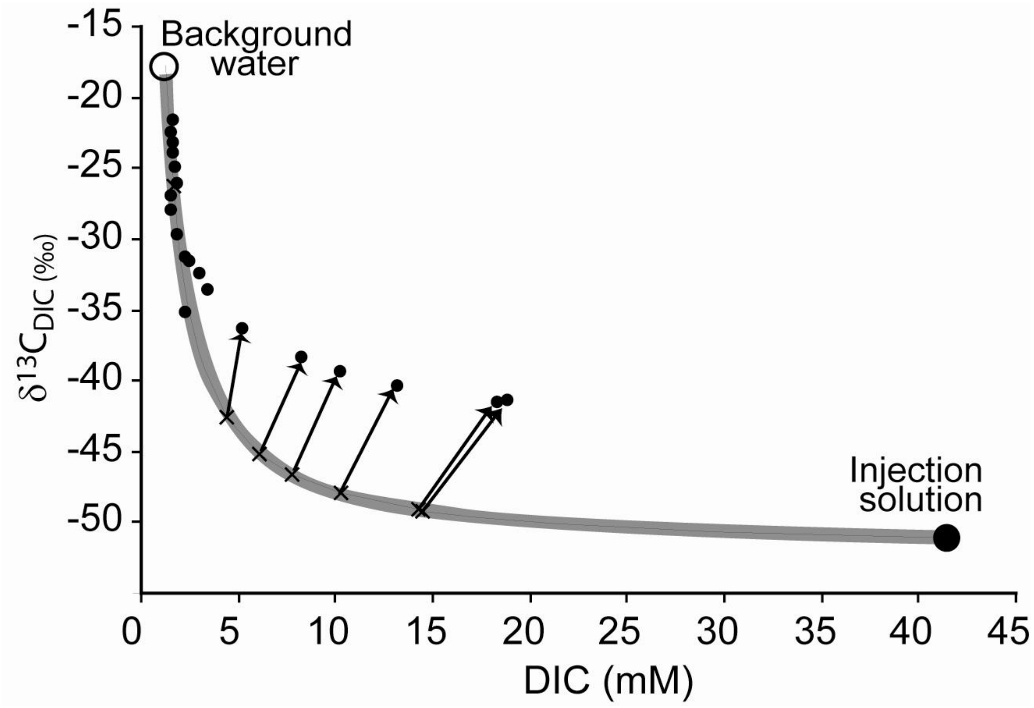
Matter et al. 2007, G^3

Calcium Source



Assayag et al. () 2008, Chemical Geology (in review)

Carbon Isotope Tracer



$$\delta^{13}C_{mix} = \left[\frac{DIC_{IW} \cdot \delta^{13}C_{IW} - DIC_{BW} \cdot \delta^{13}C_{BW}}{DIC_{IW} - DIC_{BW}}\right] + \left[\frac{DIC_{BW} \cdot DIC_{IW}\left(\delta^{13}C_{BW} - \delta^{13}C_{IW}\right)}{DIC_{mix}(DIC_{IW} - DIC_{BW})}\right]$$

$$\delta^{13}C_{DIC-add} = (DIC_{ES}\delta^{13}C_{DIC-ES} - DIC_{mix}\delta^{13}C_{DIC-mix}) / \Delta DIC$$

$\delta^{13}C_{DIC\text{-}add}$ is between -21‰ and -13‰ ($\pm$10‰)

Assayag et al. (2008), Chemical Geology (in review)

Mass Balance of CO_2 Consumption
(moles)

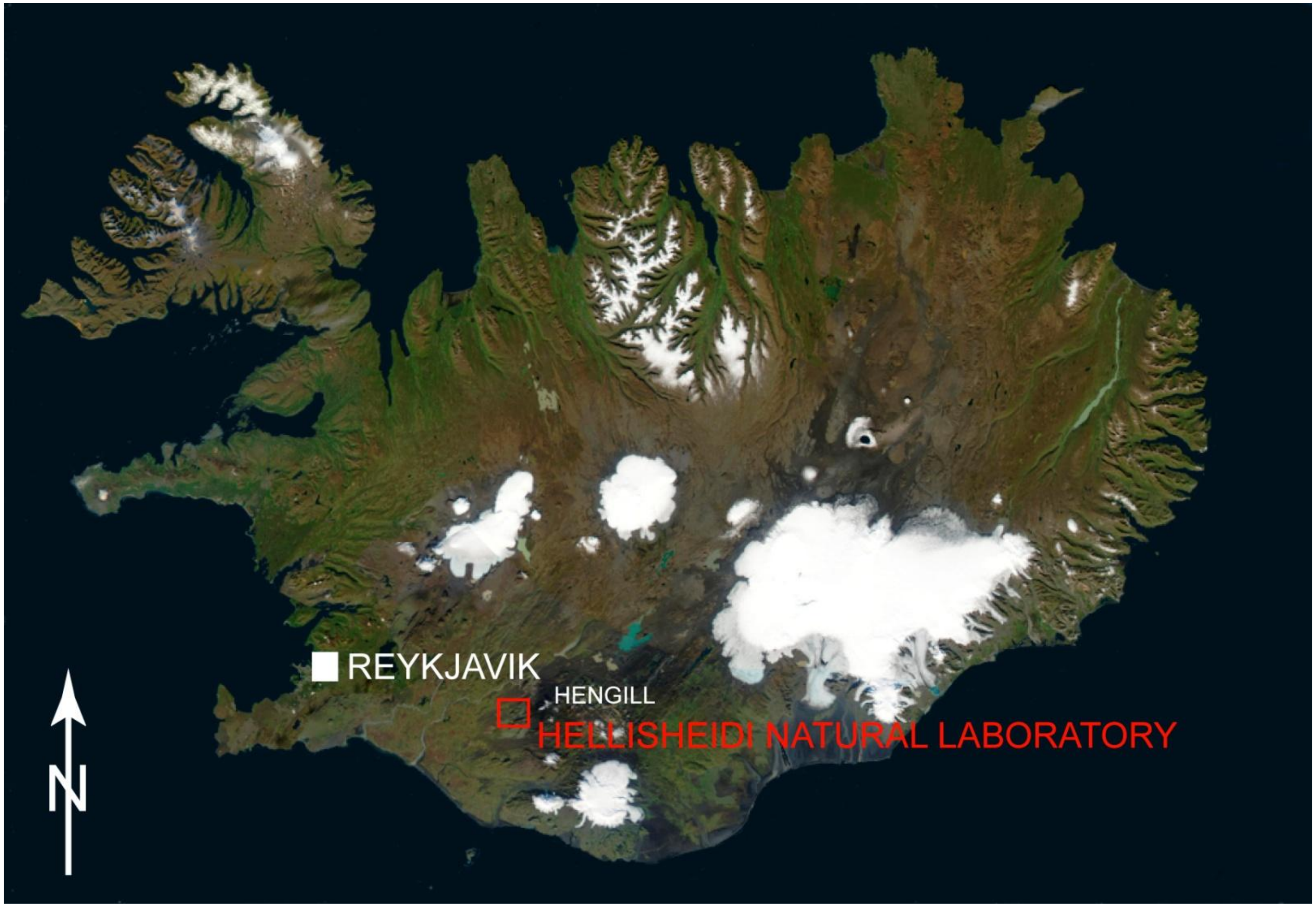
	Injected H_2CO_3	Pumped H_2CO_3	Reacted H_2CO_3	H_2CO_3 reacted by mixing	H_2CO_3 reacted by dissolution of carbonates	H_2CO_3 reacted by cation ex-change	H_2CO_3 reacted by silicate dissolution
Mean	53	25	28	**0.7**	**14.8**	**5.9**	**5**
Sigma		5	5	0.25	2	3	4.5

Carbonate Dissolution > Cation Exchange >

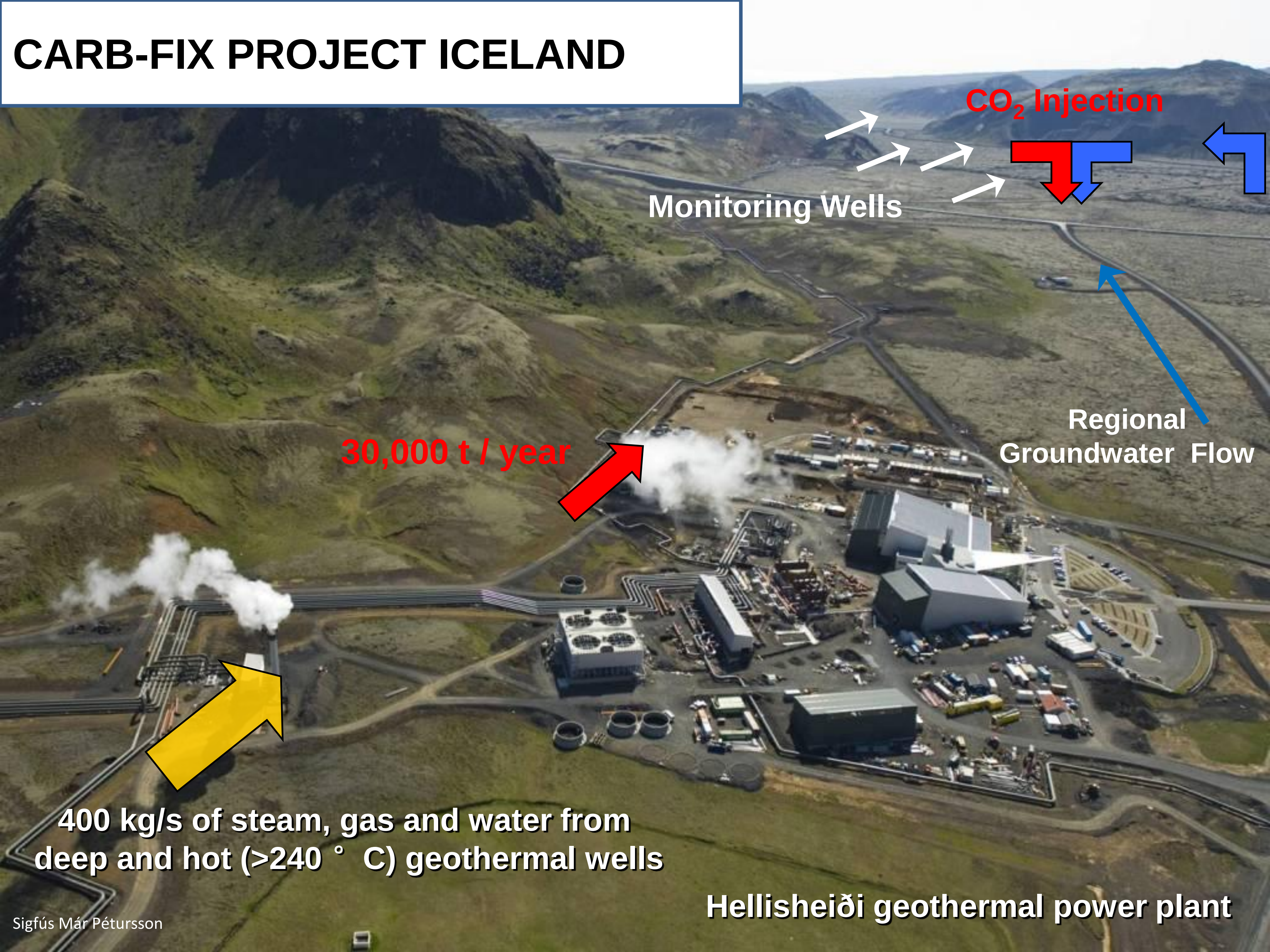
Ca, Mg Silicate Dissolution > Mixing

Carb-Fix Project, Iceland

http://www.or.is/English/Projects/CarbFix/



CARB-FIX PROJECT ICELAND



Conclusions

- **Altered surface area of pores may affect in-situ mineral carbonation capacity**
- **Dissolution of secondary minerals may significantly contribute to the CO_2 neutralization**
- Difference in dissolution rates suggest different mineral sources since the molar amount of Ca, Mg in dolerite is the same.
- **Basalt formations, such as the continental flood basalts provide the porosity and permeability as well as the geochemical reactivity needed to permanently store large amounts of CO_2 by in-situ mineralization**
- The dissolution rate increases by about 30(±15) times with a 10-fold increase in H^+ concentration for Ca, and 15(±6) times for Mg. The pH dependence of the dissolution rate for calcium is therefore twice as large as the one for magnesium.


THANK YOU